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COMPASS Final Report: Lunar Communications Terminal (LCT)

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December 2010

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1.0 Executive Summary

The Lunar Communications Terminal (LCT) COllaborative Modeling and Parametric Assessment of Space Systems (COMPASS) session designed a terminal to provide communications between lunar South Pole assets, communications relay to/from these assets through an orbiting Lunar Relay Satellite (LRS) and navigation support. The design included a complete master equipment list, power requirement list, configuration design, and brief risk assessment and cost analysis. The Terminal consists of a pallet containing the communications and avionics equipment, surrounded by the thermal control system (radiator), an attached, deployable 10-m tower, upon which were mounted locally broadcasting and receiving modems and a deployable 1 m diameter Ka/S band dish which provides relay communications with the lunar relay satellites and, as a backup, Earth when it is in view. All power was assumed to come from the lunar outpost Habitat.

Three LCT design options were explored: a stand-alone LCT servicing the manned outpost, an integrated LCT (into the Habitat or Lunar Lander), and a mini-LCT which provides a reduced level of communication for primarily robotic areas dealing as in situ resource utilization (ISRU) and remote science. Where possible all the designs assumed single fault tolerance. Significant mass savings were found when integrating the LCT into the Habitat or Lander but increases in costs occurred depending upon the level of man rating required for such designs.

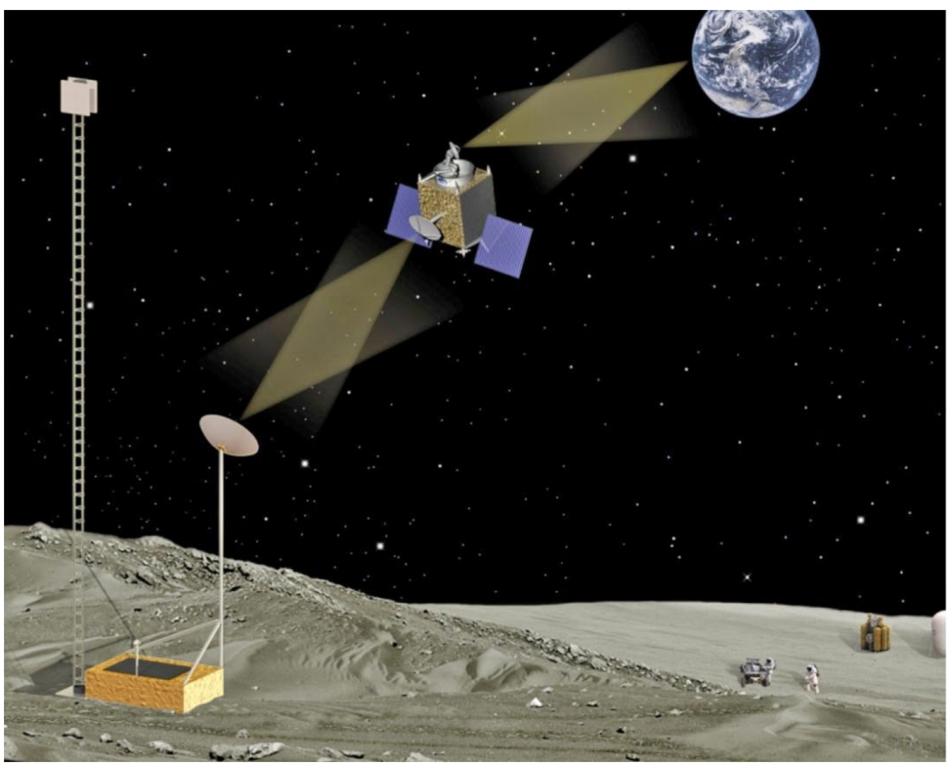


Figure 1.1—A notional artist rendering of the LCT and LRS systems in use at the lunar South Pole.

2.0 Study Background and Assumptions

2.1 Introduction

During crewed missions to the Moon, there is a need for redundant communications paths to Earth. For early, shorter duration missions, direct to Earth (DTE) and relay provide dual paths. For missions longer than the 2-wk two LRS are required for continuous coverage.

During the crewed phase, communication and navigation services are primarily provided via relay, in conjunction with a surface LCT, in support of the outpost. This LCT also provides outpost communications interconnectivity using 802-network technology.

In all cases, the nominal communications operations include all outpost vicinity communications routed through the LCT to other local users or to the relay. The LRS and LCT will provide these basic communication and navigation services:

- Forward command
- Return mission data and telemetry
- One- and two-way ranging and Doppler tracking
- Beacon signals
- In situ routing

2.2 Assumptions

Three LCT designs were completed. Some of the common assumptions are as follows:

- LCT provides Comm/Nav for piloted missions
- Delivered on Lunar Surface Access Module (LSAM)
- Seven year mission, extendable to 10 yr
- Single Fault Tolerant (except for some cases where LCT is integrated into the Habitat)

For this study, the established figures of merit (FOM) were: cost, portability, and flexibility

2.3 Growth, Contingency and Margin Policy

Because the LCT design is more akin to a small spacecraft, the mass growth allowance policy used in the science community through the Discover Proposal process is applied to this study.

Practice for Mass Properties Control for Satellites, Missiles, and Launch Vehicles. Table 2.1 shows the growth percentage based on design maturity and design area. Percent mass growth divided by design maturity and subsystem.

Once the percent growth factors are applied on a subsystem per subsystem basis, the total system growth of the design is calculated. The COMPASS system desired total average mass growth allowance (MGA) to be 30%, and an additional growth is carried at the system level in order to add up to a total system growth of 30% on the dry mass of the system.

From the Discovery Announcement of Opportunity (AO): Definitions of Contingency and Mass

Contingency (or Reserve or Growth), when added to a resource, results in the maximum expected value for that resource. Percent contingency is the value of the contingency divided by the value of the resource less the contingency.

Margin is the difference between the maximum possible value of a resource (the physical limit or the agree-to limit) and the maximum expected value for a resource. Percent margin for a resource is the available margin divided by its maximum expected value.

Power Growth: The COMPASS team uses a 30% growth factor. While instructions from Architecture Requirements Document (ARD) require an additional 10% of the dry mass of the LCT to be carried in our Master Equipment List (MEL) for attachments to attach the LCT onto the LSAM for delivery, this 10% was NOT assessed to avoid double-bookkeeping when LSAM teams begin to integrate the LCT. These attachments need to be carried either in the LSAM MEL or brought back to the LCT design as a lean on our system.

TABLE 2.1—COMPASS MASS GROWTH ALLOWANCE POLICY

Code	Design Maturity (Basis for Mass Determination)	Percent Mass Growth Allowance									
		Electrical/Electronic Components			Structure	Thermal Control	Propulsion	Batteries	Wire Harnesses	Mechanisms	Instrumentation
		0-5 kg	5-15 kg	>15 kg							
E	**Estimated** (preliminary sketches)	30	20	15	18	18	18	20	50	18	50
L	**Layout** (or major modification of existing hardware)	25	20	15	12	12	12	15	30	12	30
P	**Pre-Release Drawings** (or minor modification of existing hardware)	20	15	10	8	8	8	10	25	8	25
C	**Released Drawings** (calculated values)	10	5	5	4	4	4	5	5	4	5
X	**Existing Hardware** (actual mass from another program)	3	3	3	2	2	2	3	3	2	3
A	**Actual Mass** (measured flight hardware)	0	0	0	0	0	0	0	0	0	0
CFE	**Customer Furnished Equipment**	0	0	0	0	0	0	0	0	0	0

2.4 Mission Description

A representative LCT Deployment Timeline from LAT2 Option no. 1 (documented in LAT2 reports) is as follows:

- LCT standby power and health monitoring via LSAM during cruise and post landing
- LSAM ascent stage departs
- Space Power Unit (SPU)/Mobile Power Unit (MPU) deployments, activation and checkouts occur
- LCT is powered up and system checkouts occur while stowed
- Stand-alone LCT deployed, integrated LCT deployed on Lander or Habitat
- Ka-band antenna boom is deployed and acquires Earth
- Ka-band system acquires and tracks LRS1
- Surface communication tower is deployed and tested
- LCT operations to communicate with surface assets (e.g., rovers) and crewed LSAM and outpost components
- LCT provides communication and navigation services for subsequent LSAM landings

- Stand-alone or mini-LCT moved as needed.

2.5 System Design Trade Space

The LCT design team looked at one baseline option and two variant configurations of the LCT in order to determine impacts to cost and design. The baseline design has the LCT as a completely stand-alone item, flown to the Moon on the first unmanned LSAM lunar flight. After being deployed to the lunar surface, the LCT contains all the communications and avionics hardware necessary to provide terminal communications for the outpost to/from the LRS.

The first variant option involves building the LCT as an integral part of the Habitat or as an integral part of the Lander, leveraging off of existing communications, power, thermal, structure and avionics hardware already contained on the LSAM vehicles. The second variant is a mini-LCT, which provides lower throughput communications mainly for robotic areas such as ISRU and science locations.

2.6 Baseline System

The basic design consists of a tower, and an avionics box, with the necessary thermal to withstand the lunar environment and the necessary structure to house the electronics and withstand both the lunar environment and also the launch and flight environment of the LSAM upon which it arrives at the Moon. This LCT is delivered to the Moon by the Lunar Lander as payload and is deployed either autonomously or by astronauts.

3.0 Baseline Design

Figure 3.1 details the major components of the stand-alone LCT design. A 10 m boom holds the wireless local area network (WLAN) antenna (depicted off the scope of the cropped Figure 3.1. See Figure 3.2 for the full scale LCT). A 1 m Ka/S-band antenna is deployed on a boom on the opposite side of the electronics box from the telescoping WLAN boom.

3.1 Top Level Design (MEL and PEL)

3.1.1 Master Equipment List (MEL)

The MEL (Table 3.1) captures the bottoms-up estimation of current best estimate (CBE) and growth percentage line item by item from the subsystem designer. The table below wraps up those total masses, CBE and total mass after applied growth percentage. In order to meet the total of 30% at the system level, an allocation is necessary for system level growth. In this case, an additional 11% is carried (36.8 kg) at the system level in order to total the 104.3 kg total growth. With this system grown, the CBE dry mass of the LCT is 349.4 kg and with bottoms up growth estimations per subsystem the total mass is 417.4 kg.

TABLE 3.1—TOP LEVEL LCT MEL WITHOUT SYSTEM GROWTH

Description	CBE mass (kg)	Growth (%)	Growth mass (kg)	Total mass (kg)	Nominal power (W)	Peak power (W)
LCT System	349.4	19.5	68.0	417.4	-------	-------
LCT Tower	349.4	19.5	68.0	417.4	420.8	450.8
LCT Communications Package (from MEL 1.2)	85.6	21.8	18.6	104.2	258.2	288.2
Command and Data Handling	62.5	24.9	15.6	78.1	162.6	162.6
Power	46.8	42.9	20.1	66.9	0	0
Structures & Mechanical Systems	88.6	10.3	9.1	97.7	0	0
Thermal Control (Non-Propellant)	66.0	6.9	4.6	70.5	0	0

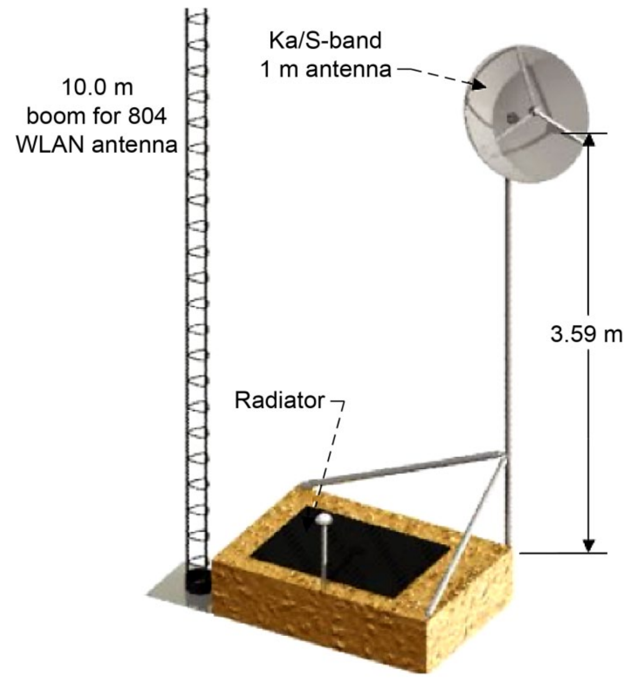


Figure 3.1—Deployed stand alone LCT (note, 10 m boom off top of picture).

Table 3.2 further details subsystems as a percent of total mass of the system. This percentage is calculated by dividing the total mass of the subsystem (after growth is added) by the total mass of the LCT Bus plus Comm.

TABLE 3.2—LCT MEL WITH SYSTEM GROWTH CALCULATIONS

LCT MEL (mass)	CBE (kg)	Growth (%)	Growth (kg)	Total mass (kg)	% of total mass
LCT Communications Package	85.6	22	18.6	104	25.0
LCT Bus	----	----	----	----	75.0
Command and Data Handling	62.5	25	15.6	78.1	18.7
Power	46.8	43	20.1	66.9	16.0
Structures and Mechanical Systems	88.6	10	9.1	97.7	23.4
Thermal Control	66.0	7	4.6	70.5	16.9
LCT Bus Mass (w/o System Growth)	263.9	18.7	49.4	313.2	
LCT Bus + Comm Package Mass	349.4	19	68.0	417.4	
Desired System Growth (Contingency)	349.4	30	104.8	454.3	
Added System Level Growth (Contingency)	N/A	11	36.9	----	
LCT Total Mass (w/ system growth)	349.4	30.00	104.8	454.3	

Note: 10% for LSAM attachments per ARD instructions not included

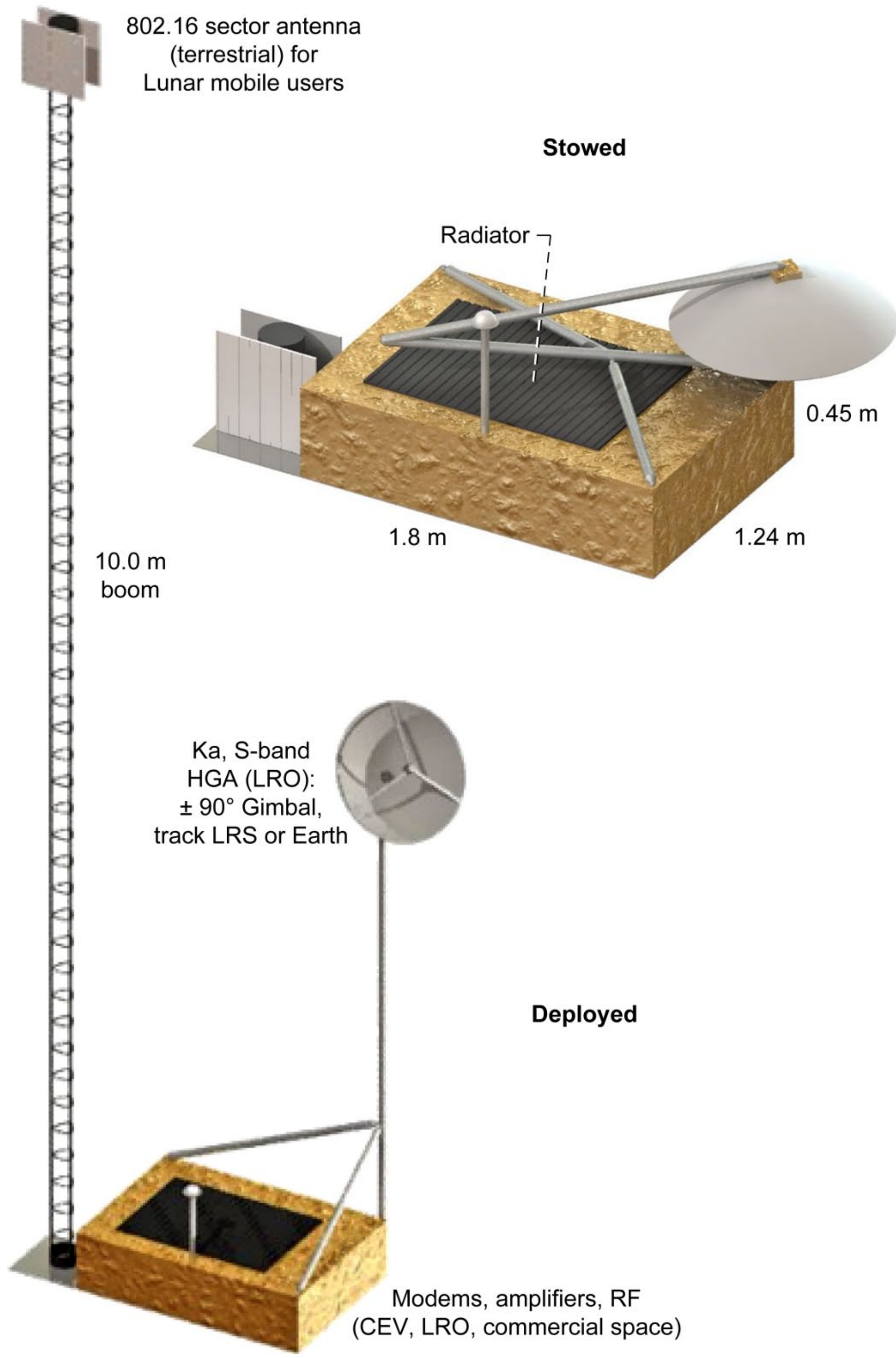


Figure 3.2—Full scale, deployed LCT and stowed LCT with major components labeled.

3.1.2 Power Equipment List (PEL)

The Power listing for nominal loads is contributed to only by the Communications and the Command and Data Handing (C&DH) subsystems. The peak power for communications is currently higher than the nominal power. Two modems are operating at the same time in the peak situation, where only one operates nominally. The power system is sized to draw enough power from the LSAM Habitat to support the peak power needs of LCT.

Table 3.3 racks up the power requirements per the two major systems of the LCT. The communications system requires 258.2 kWe nominal power, while the rest of the LCT bus (all from C&DH) requires 162.6 kWe. This makes for a total requirement of 421 kWe nominal power. The total peak power requirements are calculated similarly and are 451 kWe. This peak power increase in found in the Communications package.

TABLE 3.3—LCT PEL

LCT PEL	Nominal power (W)	Peak power (W)
LCT Communications Package	258.2	288.2
LCT Bus	162.6	162.6
C&DH	162.6	162.6
Power	0	0
Structures and Mechanical Systems	0	0
Thermal Control (Non-Propellant)	0	0
Total LCT Tower	421	451

3.2 Design Concept Drawing and Description

Figure 3.2 shows the deployed and stowed configuration of the stand-alone LCT design with dimensions of the booms and electronics housing. Note that the antenna in the stowed position points down to protect the electronics and mechanisms from lunar dust on landing.

4.0 Subsystem Breakdown

4.1 Communications

The Communications package was designed by a team at NASA Glenn Research Center (GRC) operating in parallel with the COMPASS design team. The LCT communication package was incorporated into the LCT overall COMPASS design through the use of GLIDE and the COMPASS design process. A separate report will be generated on the LCT communications package itself.

4.1.1 Communications Assumptions/Requirements

- Estimate ~120 kg, ~625 W peak
- Ka bi-directional links to LRS and for DTE supports 2 X 100 Mbps return
- S-band high gain antenna (HGA), low gain antenna (LGA) bi-directional links to LRS and DTE
- Includes 802.16 WiMax functionality for 2 to 6 km range, ≤80 Mbps
- Does not include HF (high frequency, 1 to 30 MHz) or over the horizon (OTH)
- Much Crew Exploration Vehicle (CEV), Lunar Reconnaissance Orbiter (LRO), commercial space heritage
- 802.16—terrestrial heritage
- Only 1 S-band transponder on at a time

4.1.1.1 Communications Issues With Deployment and Lander Integration

- Integration of LCT high gain Ka band antenna with high gain S band cup antenna
  - Antenna folds down on top of box in the stowed configuration; should be face down to protect from dust and plumes.
  - Propellants may stick to antenna due to cold temperatures.
  - Antenna is very sensitive to dust and ablation which increase loss due to surface roughness. If the antenna’s original surface roughness (1/40th wavelength) is increased to 1/10th, there will be a 2X (3 dB) decrease in antenna gain and twice the power will be needed for the same effective isotropic radiated power (EIRP). Receiver noise temperature will also increase.

- Selected 1-m composite antenna from LRO to save weight over aluminum and for flight heritage at new spectrum. Composite antenna is cold sensitive (cracking), needs both heaters and insulation blankets (all the time).
- Ka-antenna is on a 3.5 m boom to clear obstruction on Landers. If we can specify attitude of Lander with respect to Earth within 30° will not need this. This antenna is self-leveling.

- 802.16 WLAN sector antenna on 10-m boom
  - The 10 m boom is necessary to increase line-of-sight coverage to ~6 km around Hab.
  - Electronics were kept off boom to reduce mass but will investigate putting low noise amplifiers behind sector antennas to reduce system noise temperature.
  - Boom (Astronaut from International Space Station) retracts and folds down by the box. Boom is self-leveling.
  - Boom can be sticky to retract, so prefer human help. Tech development is needed in this area since limits Concept of Operations (CONOPS).
- Low gain S band omni antenna, Box of electronics and radiator
  - Can be repackaged to different shapes. We prefer it to lie flat for stability.
  - Radiator on top for high gain electronics. Radiator must not see the Sun. For the poles, it faces up, and the Sun is always below 5° on the horizon. Need more info for Mobile Lander. If box is mounted vertically, will need to make the radiator a fold out or tap into another radiator.
  - LCT electronics in general can withstand low temperatures of –20 to –30 °C and high temperatures of 60 to 70 °C. Will need keep warm power at all times including during launch and transit. Not carrying own batteries.

4.1.1.2 The LCT Field of View

- Ka band high gain antenna with S band high gain cup antenna
  - Ka antenna tracks LRS slowly across sky. (They are in view ~8 hr of their 12 hr elliptical orbit and ~37° max inclination). The antennas will switch from one LRS to another.
  - Alternatively, Ka antenna can track and communicate directly with Earth for part of the month. Earth rises and falls ~ 2° above/below horizon with ~1° lateral motion. LCT at Ka band could have unobstructed view of Earth when inclination is more than 1° above horizon.
  - Ka/S band high gain antenna view will be obstructed by 802.16 open boom. Need to minimize Lander/other payload obstructions. Ka/S band high gain antenna will be able to be gimbaled through entire hemisphere after deployment on short mast. When HGA is deployed on Lander from high bay, the short mast allows it to have view the Earth and track LRS even if Lander is oriented with Ka on opposite side of Lander from Earth.
- 802.16 WLAN sector antenna on 10-m boom
  - Antenna must be at least 10 m above surface to increase line-of-sight range to the desired ~6 km. This can be accomplished through a combination of boom and Lander height.
- S band omni antenna/radiator
  - Must not face Sun. At the South Pole, radiator point face up while Sun remains below 5° from horizon.

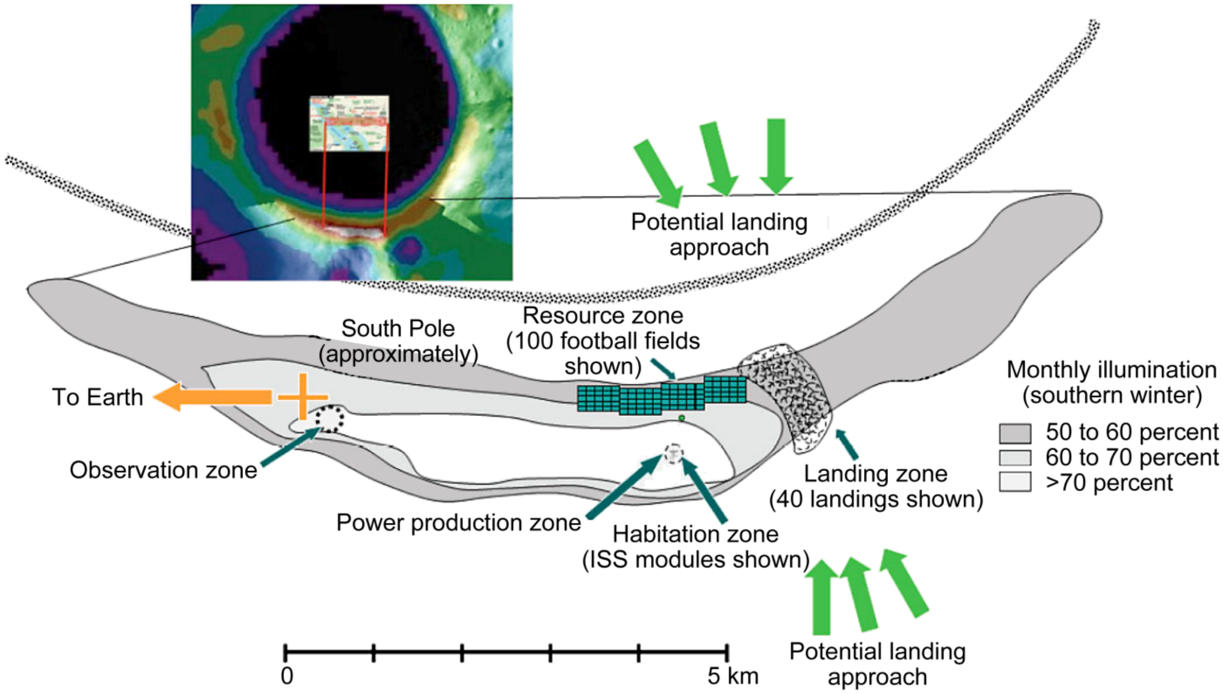


Figure 4.1—Illumination of the lunar South Pole landing zone and landing approach details.

Figure 4.1 illustrates the projected landing sites for the lunar South Pole mission. The grey zones show the illumination percentage for power and communications sizing.

4.1.2 Communications Design and MEL

4.1.3 Communications Analytical Methods

- Sized down from the ATS-3 150 Mbps modulator designed by Dr. Chen at Comdev (a developer of the modulator) using LCT requirements of power and mass for a complete 100 Mbps modulating modem.
- WLAN base station based upon medium power, not high power commercial base station

TABLE 4.1—LCT COMMUNICATIONS SYSTEM DETAILED MEL

Description	Qty	Unit Mass (kg)	CBE Mass (kg)	Growth (%)	Growth Mass (kg)	Total Mass (kg)	Nominal Power (W)	Peak Power (W)
LCT System	-	---	85.6	21.8	18.6	104.2	----	----
LCT Communications Package	-	---	85.6	22	18.6	104.2	258.2	288.2
Gateway to Earth hardware	0	0.0	0.0	0	0.0	0.0	----	----
Communications hardware	-	---	49.3	------	8.0	57.3	----	----
Ka-band/S-band HGA	-	---	5.9	------	1.8	7.7	----	----
HGA (1-m dish)	1	5.9	5.9	30	1.8	7.7	0.0	----
Ka-band radio	-	---	35.2	----	5.6	40.8	----	----
Ka band diplexer (in dual diplexer)	1	0.5	0.5	10	0.1	0.6	0.0	----
Ka feed (in Ka/S antenna)	1	0.9	0.9	21	0.2	1.1	0.0	----
2 x 1 Baseball Switch (computer controlled)	2	0.1	0.2	10	0.0	0.2	0.0	----
23 GHz low noise block (receiver, includes downconverter)	2	0.9	1.8	20	0.4	2.2	7.2	7.2
Ka-band 2 x 2 intermediate frequency switch	3	0.1	0.4	10	0.0	0.4	0.0	----
100 Mb/s modem	2	10.0	20.0	15	3.0	23.0	30.0	60.0
26 GHz power amplifier (40 W TWTA)	2	1.5	3.0	3	0.1	3.1	0.0	----
TWTA Electrical Power Conditioning Unit	2	1.5	3.0	10	0.3	3.3	80.0	80.0
Passive combiner network with upconverters	1	5.0	5.0	30	1.5	6.5	8.0	8.0
Passive components, couplers, switches, etc.	2	0.2	0.4	10	0.0	0.4	0.0	----
SN TDRSS S-band radio	-	---	8.2	----	0.7	8.9	----	----
S band diplexer (in HGA dual diplexer and LGA)	2	0.5	1.0	8	0.1	1.1	0.0	----
2 x 2 Baseball Switch (computer controlled)	1	0.1	0.1	18	0.0	0.1	0.0	----
S band feed (in Ka/S band antenna)	1	2.8	2.8	8	0.2	3.0	0.0	----
S-band cup dipole antenna	1	0.7	0.7	3	0.0	0.7	0.0	----
S-band test couplers	2	0.2	0.4	3	0.0	0.4	0.0	----
6 Mb/s transceiver	2	1.6	3.2	10	0.3	3.5	43.0	43.0
Onboard Network and Avionics	-	---	1.0	----	0.2	1.2	----	----
Network Hardware	-	---	1.0	----	0.2	1.2	----	----
Router/Encryption Device	2	0.5	1.0	15	0.2	1.2	20.0	20.0
Ion trap space clock with distribution amplifier	0	2.0	0.0	20	0.0	0.0	0.0	0.0
Lunar Surface Network	-	---	27.5	----	8.8	36.3	----	----
Wireless LAN (802.xx)	-	---	16.5	----	6.6	23.1	----	----
Base Station (802.16e)	3	5.5	16.5	40	6.6	23.1	70.0	70.0
24 x 1 switch	0	2.0	0.0	10	0.0	0.0	0.0	0.0
WLAN Antenna	-	---	11.0	----	2.2	13.2	----	----
Sector antenna	2	5.5	11.0	20	2.2	13.2	0	----
Subtotal	-	---	77.8	----	17.0	94.8	----	----
Cabling to connect internal components	-	---	7.8	21	1.6	9.4	----	----
Grand total	-	---	85.6	----	18.6	104.2	----	----

4.1.4 Communications Risk Inputs

The three communications risk inputs were:

1. Antenna Pointing Error

Given the extreme temperature changes in space; there is a possibility that pointing errors and performance degradation could occur due to a surface distortion of the reflector antenna.

Context: Pointing error could occur due to extreme temperature changes in space, resulting in loss of antenna gain and higher sidelobe.

Mitigation Strategy: Thermal shielding of the antenna.

2. Premature LCT Failure/Loss of LCT

Given the astronaut interfaces in deployment and servicing; there is a possibility that there will be pre-mature failure and ultimately, loss of the LCT.

Context: The environment on the Moon is not conducive to fine motor skills, which the LCT might need for deployment and/or servicing.

Mitigation Strategy: Ensure sufficient astronaut and robotic interface testing with LCT before deployment and operations.

3. Health Management

Given that unexpected failures can occur in electrical/mechanical/structural systems; there is a possibility that a critical failure can occur, causing loss of communications and/or navigation capability.

Context: Health Technology (i.e., fault detection, identification, and repair) can be designed into the system to provide long term functionality.

Mitigation Strategy: Electrical/Mechanical/Structural systems should be designed with fault tolerance as a requirement.

4.1.5 Communications Findings

- 100 Mbps demodulator requires development by LRS to be completed (technology development)
- Possibly significant development required for space qualified 802.16 system (more technology development)
- HGA will likely "look through" sector antenna if located as illustrated—needs detailed radio frequency interference (RFI) analysis
- Accommodation of "dissimilar voice" requirement through LRS via S-band—not fully defined or understood

4.2 C&DH

4.2.1 C&DH Requirements

- Storage Array for 24 hr of storage (0.3 TB)
- Avionics for systems command, control, and health management
- Use of highly stable oscillators
- Fiber optics comm. port to Habitat
- Functionality of the Avionics Systems is provided in Figure 4.2

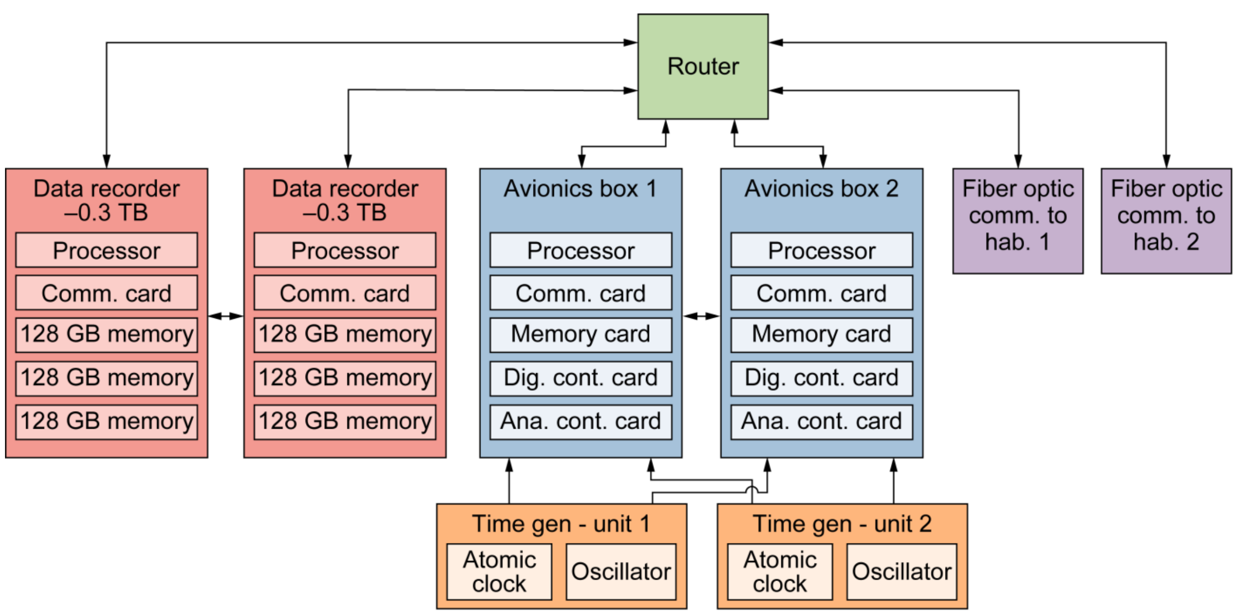


Figure 4.2—LCT Avionics functional block diagram.

4.2.2 C&DH Assumptions

- Single fault tolerant avionics
- Storage array will use next gen. rad. hardened storage, 128 GB per card
- 100 krad avionics
- Cabling is calculated as 10% of the avionics hardware

4.2.3 C&DH Design and MEL

- Avionics components based on commercially available components from British Aerospace (BAE). All avionics assume 3U-160 form factor cards.
- Avionics Box contains a processor and storage card for general LCT command and control. A comm. card is included for communication with the LCT router. The package included any necessary DC-DC converters, filter, and electromagnetic interference (EMI) shielding. There are two independent avionics boxes for single fault tolerance.
- An ultra-stable oscillator (USO) is included in the avionics package. The oscillator is from Frequency Electronics and is the same unit used in the global positioning satellites (GPS). There are two independent USOs for single fault tolerance.
- Fiber Optic Comm. is included in the avionics package. This is a fiber optic comm. card in an enclosure and includes any necessary DC-DC converters, filter, and EMI shielding. There are two independent fiber optic comm. boxes for single fault tolerance.
- Data Recorder is based on future 128 GB storage cards. A processor is included for managing the storage array. A comm. card is included for communications to the LCT router. The Data Recorder is not single fault tolerant but it is assumed the cards will be used in a fault tolerant configuration such as redundant array of independent disks 5 (RAID 5).

TABLE 4.2—LCT C&DH DETAILED MEL

Description	Qty	Unit mass (kg)	CBE mass (kg)	Growth (%)	Growth (kg)	Total mass (kg)	Nominal power (W)	Peak power (W)
LCT System	-	----	347.7	19.4	67.5	415.2	------	------
C&DH	-	----	62.5	24.9	15.6	78.1	162.6	162.6
Electronics	-	----	44.8	19.7	8.8	53.6	------	------
Data recorder	2	11.0	22.0	20.0	4.4	26.4	72	72
General Avionics Processor	2	11.0	22.0	20.0	4.4	26.4	65	65
Time Generation Unit	2	0.4	0.8	3.0	0.0	0.8	0.6	0.6
Star Tracker	0	0.0	0.0	0.0	0.0	0.0	0	0
Antenna controls	-	----	0.0	0.0	0.0	0.0	------	------
Antenna control electronics S/Ka-band no. 1	0	0.0	0.0	0.0	0.0	0.0	0	0
Antenna control electronics S/Ka-band no. 2	0	0.0	0.0	0.0	0.0	0.0	0	0
Misc no. 1	0	0.0	0.0	0.0	0.0	0.0	0	0
Cabling and associated hardware	-	----	13.7	40.4	5.5	19.3	------	------
Command and Control Harness (data)	1	5.3	5.3	50.0	2.7	8.0	0	0
Fiber Optic Comm Port	2	2.2	4.4	20.0	0.9	5.3	5	5
Fiber Optic Cabling and reel	1	4.0	4.0	50.0	2.0	6.0	0	0
Misc	-	----	4.0	30.0	1.2	5.2	------	------
Atomic Clock	2	2.0	4.0	30.0	1.2	5.2	20	20

4.2.4 C&DH Trades

No trades were performed on avionics for the baseline mission. However, when integrated with the Habitat and Lander, some items were removed from the LCT design that could now be assumed on the hab or Lander. In addition, some items were removed for the mini-LCT design.

4.2.5 C&DH Analytical Methods

The Avionics system consisted of several items. The following gives an itemized description of their components and functions.

- General Avionics Processor
  - System initialization
  - Antenna tower deployment
  - Solar array deployment
  - Systems health and status management
  - Power management, control, distribution, and load shedding
  - Battery regulation and management
  - Thermal system management—includes control of pumps, valves, and heaters
  - System fault detection and correction
  - Time synchronization
  - Time stamping
  - Router management
  - Comm. system management (includes WAN, internal LCT comm., and fiber optic comm. to Habitat)
- Data Recorder
  - Storage array monitoring and health management, including fault detection and correction
  - Synchronization of data between redundant data recorders
  - Buffering of data from WAN and LAN for transmission to Earth
- Time Generation Unit
  - System time generation, used by the General Avionics Processor for time synchronization
- Fiber Optic Comm. to Habitat
  - Provide a hard line comm. interface between the Habitat and the LCT router

4.2.6 C&DH Risk Inputs

Data Recorder Design Based on Future Technology

Given that the data recorder design is based on future technology that may not be available for inclusion in the LCT; there is a possibility that the resulting design will be a larger and/or heavier data recorder.

Context: The data recorder serves as a buffer between lunar communications and Earth. It must have enough storage to buffer data when communication is not available.

Mitigation Strategy: The LCT design must take into consideration that the data recorder may be larger than initially anticipated.

Avionics System Functions Not Completely Defined

Given the functions of the avionics system are not well defined; there is a possibility that the avionics hardware may be considerably over or under designed.

Context: The avionics system components are currently spec'ed out for what is perceived to be their functionality. Given the immaturity of the LCT design, the size, complexity, and mass of the avionics components could be significantly different from this initial estimate

Mitigation Strategy: Design the avionics system with the largest reasonable growth factor to account for changes in the system's functionality.

4.2.7 C&DH Findings

- The 0.3 TB storage array is design around future technology. If the technology for the storage array is not yet available when the LCT is built, this component could be larger than expected.
- The functions of all the avionics systems are not well understood. It may be possible to combine the capabilities of different systems into a small avionics package. Inversely the avionics package could be under designed leading to growth of the system beyond the assumed growth margin.

- Fiber optic connections can be very susceptible to dust. The system design currently includes an optical fiber connection that must be made with the Habitat, thus potentially exposing a fiber optic connection to the dust lunar environment. If the fiber optic connection becomes dirty, this link between the Habitat and the LCT could become inoperable.

4.3 Electrical Power System

4.3.1 Power Requirements

The LCT system requires an uninterrupted power supply from the outpost.

4.3.2 Power Assumptions

The LCT power requirement is assumed to be supplied by an outpost power network. The network is fault-tolerant and capable of providing both daytime and solar eclipse-time power. A 30% margin is assumed on the specified peak power requirement.

4.3.3 Power Design and MEL

The power system consists of a long power cable and spool from the outpost to the LCT, the on-board wire harness, and a 270 Vdc to 28 Vdc converter to convert the outpost power to the on-board bus voltage. The long cable is a 10 AWG 200 m cable with 25% additional length for required distance to Lander site.

The Power MEL was designed in order to allow for freedom of design by the subsystem engineer. Note the existence of a battery and solar array in the MEL listing have no mass because neither were used in this design but were place holders for future trades to be run. Neither was used in this LCT design since all power was coming from the outpost Habitat.

TABLE 4.3—LCT POWER SYSTEM DETAILED MEL

Description	Qty	Unit mass (kg)	CBE mass (kg)	Growth (%)	Growth (kg)	Total mass (kg)
LCT System	-	-----	347.7	19.4	67.5	415.2
Power	-	-----	46.8	42.9	20.1	66.9
Battery System	-	-----	0.0	0.0	0.0	0.0
Solar Array	-	-----	0.0	0.0	0.0	0.0
Power Management & Distribution	-	-----	46.8	42.9	20.1	66.9
Power management/control electronics	1	14.6	14.6	30.0	4.4	19.0
Power distribution/monitoring internal wiring harness	1	6.2	6.2	50.0	3.1	9.3
Long Distance Power Transmission Cable (270 v)	1	24.0	24.0	50.0	12.0	36.0
Long Distance Power Transmission Cable Spool	1	2.0	2.0	30.0	0.6	2.6

4.3.4 Power Trades

The overall mass is sized based on distance from the outpost (currently 200 m), overall power requirement, and the choice of 28 V dc bus (rather than 270 V dc). A shorter distance, lower power requirement, or a 270 V dc bus would each reduce power system mass. No further power system sizing trades were done at this time.

4.3.5 Power Analytical Methods

The Power Management and Distribution (PMAD) models are based on the work of Ken Metcalf, NASA CR–189225. The cable design is from the MIL-W-22759/34 specification.

4.4 Structures and Mechanical Systems

4.4.1 Structures and Mechanical Systems Requirements

Provide sufficient space to house the necessary hardware for avionics, communications, propulsion, and power.

- Contain necessary instrumentation and hardware
- Support antennas with minimal vibration
- Shield sensitive hardware against lunar dust
- Withstand applied loads from launch vehicle and provide sufficient stiffness and vibration damping
- Withstand lunar gravitational load while deployed and operating
- Withstand potential inadvertent loads from close proximity operations

4.4.2 Structures and Mechanical Systems Assumptions

- Material: Aluminum 2090
- Deployable lattice boom for antenna
- Space frame with tubular members
- Composite sandwich structure panels
- Welded and threaded fastener assembly

4.4.3 Structures and Mechanical Systems Design and MEL

The LCT structure consisted of a space frame and composite sandwich construction panels to house and support attached/mounted hardware. Figure 4.3 shows the LCT in a stowed configuration as it would be upon landing on the Moon. The structure had to both support the tower when deployed and provide a method to stow during launch.

TABLE 4.4—LCT STRUCTURES AND MECHANICAL SYSTEMS DETAILED MEL

Description	Qty	Unit mass (kg)	CBE mass (kg)	Growth (%)	Growth (kg)	Total mass (kg)
LCT System	-	----	347.7	19.4	67.5	415.2
Structures & Mechanical Systems	-	----	88.6	10.3	9.1	97.7
Primary Structures	-	----	50.4	15.0	7.6	58.0
Legs	0	0.0	0.0	15.0	0.0	0.0
Boom for 802.x WLAN	1	18.0	18.0	15.0	2.7	20.7
Main Structure	1	32.4	32.4	15.0	4.9	37.2
Self-Leveling hardware	0	0.0	0.0	15.0	0.0	0.0
Installation	-	----	25.0	2.3	0.6	25.6
C&DH Installation	1	2.9	2.9	4.0	0.1	3.1
Communications Package Installation	1	6.4	6.4	4.0	0.3	6.7
Power Installation	1	3.5	3.5	4.0	0.1	3.6
Thermal Installation	1	1.8	1.8	4.0	0.1	1.8
Attachment fittings to LSAM	1	10.4	10.4	0.0	0.0	10.4
Mechanisms	-	----	13.1	7.6	1.0	14.1
Separation mechanism - LSAM Interface mount	0	0.0	0.0	10.0	0.0	0.0
Antenna Attachment - S/Ka band no. 1	0	0.0	0.0	0.0	0.0	0.0
Antenna gimbals - S/Ka band no. 1	2	4.4	8.8	4.0	0.4	9.2
Antenna Attachment - S/Ka band no. 2	0	0.0	0.0	0.0	0.0	0.0
Antenna gimbals - S/Ka band no. 2	0	0.0	0.0	0.0	0.0	0.0
Environmental Shield	0	0.0	0.0	0.0	0.0	0.0
SPU cable deployment system	0	0.0	0.0	0.0	0.0	0.0
Dish Antenna (Ka) Boom	1	4.3	4.3	15.0	0.6	5.0

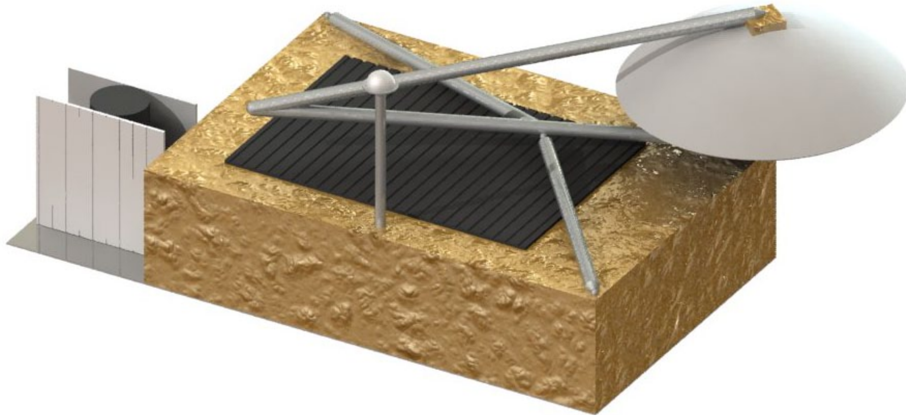


Figure 4.3—LCT stowed configuration.

4.4.4 Structures and Mechanical Systems Trades

The space frame was sized to accommodate the volume requirements of antennas and instrumentation while providing room for instrumentation and fitting within confines of launch vehicle.

4.4.5 Structures and Mechanical Systems Analytical Methods

Preliminary structural analysis with given launch loads.

4.4.6 Structures and Mechanical Systems Risk Inputs

Potential Structural Failure

Given the nearby operations and space debris on the Moon; there is a possibility that foreign object impact and/or induced vibrations may diminish performance or incapacitate the system.

Context: Impact damage may cause the system to collapse if any primary structural member is incapacitated. In addition, vibrations can diminish instrument performance and potentially lead to long term structural failure due to fatigue.

Mitigation Strategy: The structure should be designed to NASA standards to withstand a given impact and to have sufficient dampening to minimize issues with vibrations.

Mechanical Structural Failures

Given the extreme environmental conditions of the Moon; there is a possibility that the mechanical structures (gimbals, booms, antennas) may fail due to dust, LSAM propulsion exhaust, debris, and extreme temperatures.

Mitigation Strategy: Ensure sufficient design and testing for such extreme environments. Ensure proper protection of mechanical components from the environment.

4.4.7 Structures and Mechanisms Recommendation

FE analysis will be necessary to determine stresses and displacements along with a modal analysis for vibrations.

4.5 Thermal Control

4.5.1 Thermal Requirements

The thermal system must keep the electronics in a thermally regulated environment, and provide heat radiation for all of the communications components. These components included the booms and antenna as well as their control electronics.

4.5.2 Thermal Assumptions

The thermal assumptions consisted of assumptions as to the temperatures on the lunar surface, and the radiators and heaters necessary to protect the communications and electronics elements of the LCT.

4.5.3 Thermal Design and MEL

- Radiator, horizontal orientation which provides the greatest cooling capability at the polar location
- Variable conductance heat pipes for transferring heat to the radiator. This provides a self regulating thermal control system.
- Cold plates for extracting the heat from the electronics
- Multi-layer-insulation (MLI) for insulating the electronic boxes
- Internal electrical heaters for maintaining the minimum required internal temperature.
- Thermocouples, data acquisition and controls for operating the heaters.
- MLI and heaters on the tower to maintain is required temperature.

4.5.4 Thermal Risk Inputs

Heat Pipe Failure

Given the failure of one or more heat pipes due to an internal fluid leak; there is a possibility that this leak would result in the failure of electronics which are being cooled by the heat pipe system.

Context: Leaks in the heat pipes can be caused by stress cracks, weld failures, or micro meteors

Mitigation Strategy: Utilize micro meteor shielding on any exposed heat pipes (those going to the radiator), inspect any welds in the pipes, and design the system to minimize stress on the heat pipes.

Heater Failure

Given the failure of one or more internal heaters used to maintain a minimum electronics and tower temperature during the lunar night time; there is a possibility that this failure could lead to failure of the electronics or the ability to retract the communications tower.

Mitigation Strategy: Utilize redundant heaters and MLI in order to minimize any effects of a heater failure.

TABLE 4.5—LCT THERMAL CONTROL SYSTEM DETAILED MEL

Description	Qty	Unit mass (kg)	CBE mass (kg)	Growth (%)	Growth (kg)	Total mass (kg)
LCT System	----		347.7	19.4	67.5	415.2
Thermal Control (Non-Propellant)	----		66.0	6.9	4.6	70.5
Active Thermal Control	----		17.0	6.7	1.1	18.1
Heaters	6	0.1	0.9	15.0	0.1	1.0
Thermal Control/Heaters Circuit	6	0.2	1.2	18.0	0.2	1.4
Data Acquisition	6	1.0	6.0	10.0	0.6	6.6
Thermocouples	150	0.010	1.5	5.0	0.1	1.6
Thermal Control Switch	12	0.2	2.4	5.0	0.1	2.5
Tower Heaters	50	0.1	5.0	0.0	0.0	5.0
Passive Thermal Control	----	-----	49.0	7.0	3.4	52.4
Heat Sinks	6	3.5	20.8	10.0	2.1	22.9
Heat Pipes	6	0.5	3.2	13.0	0.4	3.7
Radiators	1	5.2	5.2	13.0	0.7	5.9
MLI	1	1.4	1.4	10.0	0.1	1.6
Temperature Sensors	50	0.0	0.5	5.0	0.0	0.5
Phase Change Devices	0	0.0	0.0	0.0	0.0	0.0
Thermal Coatings/Paint	1	0.9	0.9	5.0	0.0	1.0
RHU (if applicable)	0	0.0	0.0	0.0	0.0	0.0
Radiator MMOD	1	0.4	0.4	10.0	0.0	0.4
Tower MLI	1	16.6	16.6	0.0	0.0	16.6
Semi-Passive Thermal Control	----	------	0.0	0.0	0.0	0.0

5.0 Avionics Software

5.1 Software Modeling Objectives

- To understand the functional requirements that the LCT is designed to meet (software is strongly affected by hardware design)
- To develop software cost estimates based on the LCT functional requirements, especially the LCT avionics functionality

5.2 Assumptions

- RTOS (such as VxWorks or RT Linux) for a single-board computer or a multipurpose computer to be ported to the LCT system/subsystems
- Internetwork operating system (IOS) (similar to Cisco IOS) to be ported to LCT router
- IP-based networks to be supported
- Comply with all security protocols defined by C3I
- Any new software to be developed will be C/C++ or Ada or a combination of these languages for mission critical such as avionics. For software cost estimate, use C.
- Source lines of code (SLOC) is a count of the text of the source code including comment lines, neither “physical” nor “logical” is considered as the types of SLOC measures

5.3 Approach

- Software sizing and estimation are based on mainly on the LCT hardware functionality for avionics and communication and navigation
- Other sources and references are also used for estimating number of SLOC. For example, labor cost or full time equivalent (FTE) is for this purpose.

6.0 Cost and Risk

6.1 Costing

The costing for the LCT options were reported in another presentation for LAT2.

6.2 Risk Analysis and Reduction

The management of risk is a foundational issue in the design, development and extension of technology. Each subsystem was tasked to write a risk statement regarding any concerns, issues and ‘ah ha’s’. Mitigation plans would focus on recommendations to alleviate, if not eliminate the risk.

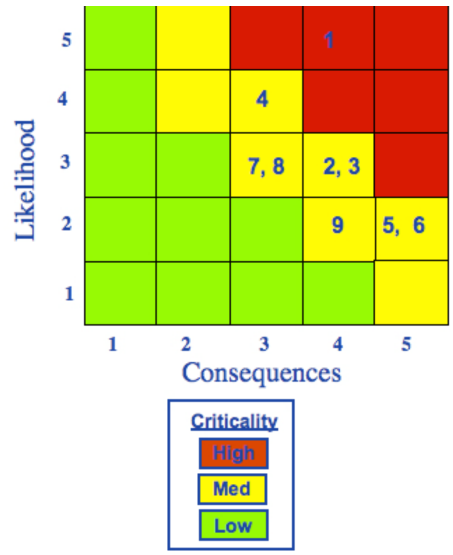
6.2.1 Assumptions

- Risk attributes are based on CEV risk values.
- Risk List is not based on trends or criticality.
- Some mitigation plans are offered as suggestions.
- Based on the derived model of this study only.

6.2.2 LCT Risk List

TABLE 6.1—STAND ALONE LCT RISK LISTING MATRIX

No.	L x C	Team	Risk Title
1	5 x 4	Antenna	Antenna Pointing Error
2	3 x 4	Avionics	Avionics System Functions not completely defined
3	3 x 4	Communications	Data Recorder Design based on Future Technology
4	4 x 3	Deployment	Premature LCT Failure/Loss of LCT
5	2 x 5	Thermal	Heat Pipe Failure
6	2 x 5	Structural	Potential Structural Failure
7	3 x 3	Communications	Health Management
8	3 x 3	Structural	Mechanical Structural Failures
9	2 x 4	Thermal	Heater Failure



6.2.3 Risk Summary

- Areas of concern for this study include:
  - Performance degradation of antenna
  - Design of avionics
  - Available technology for communications
  - Thermal protection of electronics
  - Impact damage to the structures

These risks, with proper pro-active planning can be mitigated early to avoid becoming problems late in the development life cycle.

7.0 Trade Space Iterations

Additional questions came from HQ after the completion of the LCT design session. Specifically, two trades were requested. One looked at the implication of integrating the LCT directly onto either the Habitat or the Lunar Lander, and the other looked at making a mini-LCT with reduced capabilities, for use for things like ISRU plants deep within craters.

The ground rules for both the Habitat and Lunar Lander integrated configurations of the LCT were as follows: no assumptions could be made on using assets in communications or avionics on the Lander or Habitat.

7.1 Integrated LCT—Habitat/Lander Deployed at the South Pole

This LCT design was assumed to be deployable at the south lunar pole. A second LCT design required deployment anywhere on the lunar surface, without limiting its location to the south lunar pole. In modeling both cases, the assumptions on thermal were the same in both. Thermal was the only subsystem which might have yielded differentiation in configuration design. Therefore there is only one integrated LCT design.

7.1.1 Integrated LCT Design and MEL

Figure 7.1 shows the stowed configuration of the LCT on top of a representative minimum ascent Lunar Lander. At the time of the study, a definitive Lunar Lander was not available. For the purpose of the integration, the LCT is placed on the top plate, in front of the minimum ascent stage and in the stowed configuration for launch and landing. Figure 7.2 shows a close up of the stowed configuration. The LCT is only deployed after the ascent stage has left the surface. Note the two graphics are not in scale with each other.

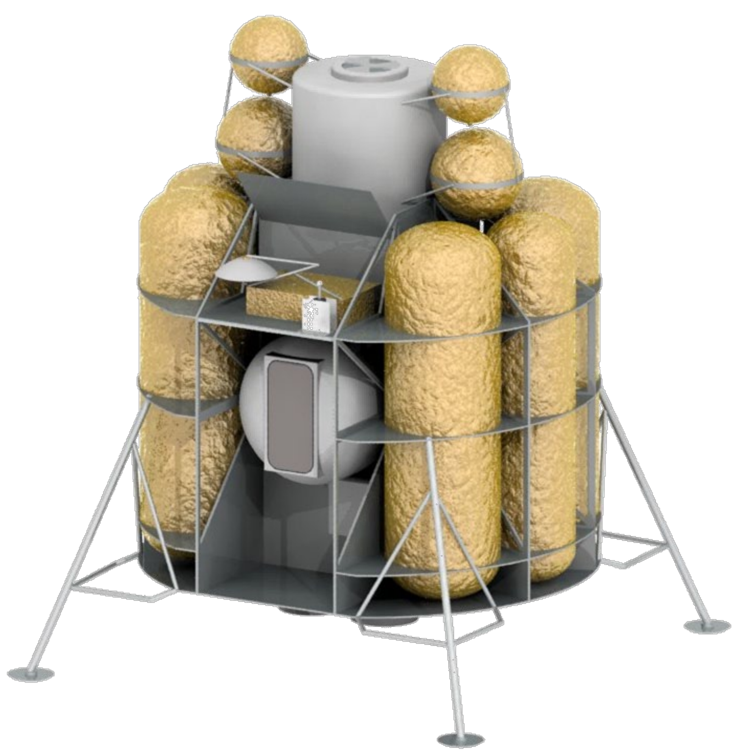


Figure 7.1—Current mini-Habitat version of the Lunar Lander with stowed integrated LCT.

Figure 7.2—Close-up view of stowed integrated LCT on the current version of the mini-Habitat Lunar Lander.

Table 7.1 above presents the summary of the bottoms-up of masses of the subsystems. Note that the total average subsystem mass growth allowance (MGA) for the integrated LCT is 18%. An additional 12% (34.9 kg) is carried as system level growth in order to meet the study required total system level growth of 30%. The CBE mass of the integrated LCT is 282.5 kg. With 30% growth mass (84.7 kg), the total mass, with growth, of the integrated LCT is 367.2 kg.

TABLE 7.1—INTEGRATED LCT MEL WITH SYSTEM GROWTH CALCULATIONS

LCT MEL (mass)	CBE (kg)	Growth (%)	Growth (kg)	Total mass (kg)	% of total mass
LCT Communications Package	85.6	22	18.6	104	31.3
LCT Bus	-----	----	----	-----	68.7
C&DH	62.5	25	15.6	78.1	23.5
Power	7.0	39	2.7	9.7	2.9
Structures and Mechanical Systems	88.6	10	9.1	97.7	29.4
Thermal Control (Non-Propellant)	38.8	10	3.9	42.7	12.8
LCT Bus Mass (Without System Growth)	196.9	15.9	31.3	228.2	
LCT Bus + Comm Package Mass	282.5	18	49.9	332.4	
Desired System Growth (Contingency)	282.5	30	84.7	367.2	
Added System Level Growth (Contingency)	N/A	12	34.9	-------	
LCT Total Mass (With System Growth)	282.5	30	84.7	367.2	

7.1.2 Communications—Integrated LCT

The ground rule assumption of the integrated LCT design was that the communications system could not use any assets already on the Habitat or Lander. Therefore the communications system in the integrated LCT was that of the original LCT design of section 4.1.

7.1.3 C&DH—Integrated LCT

The ground rule assumption of the integrated LCT design was that the C&DH system could not use any assets already on the Habitat or Lander. Therefore the C&DH system in the integrated LCT was that of the original LCT design of section 4.2.

7.1.4 Power—Integrated LCT

The power system was drastically reduced from the original LCT design since the lengthy cable that was spooled from the Lander to the deployed LCT was no longer needed. Table 7.2 shows the MEL of the integrated LCT power system.

TABLE 7.2—INTEGRATED LCT POWER SYSTEM DETAILED MEL

WBS no.	Description	Qty	Unit mass (kg)	CBE mass (kg)	Growth (%)	Growth (kg)	Total mass (kg)
1	LCT System	-	---	282.5	17.7	49.9	332.4
1.1	LCT Tower-Integrated	-	---	282.5	17.7	49.9	332.4
1.1.3	Power	-	---	7.0	38.6	2.7	9.7
1.1.3.3	Power Management & Distribution	-	---	7.0	38.6	2.7	9.7
1.1.3.3.a	Power management/control electronics	1	4.0	4.0	30.0	1.2	5.2
1.1.3.3.b	Power distribution/monitoring wiring harness	1	2.0	2.0	50.0	1.0	3.0
1.1.3.3.c	Long distance power transmission cable (270 v)	1	1.0	1.0	50.0	0.5	1.5
1.1.3.3.d	Long distance power transmission cable spool	1	0.0	0.0	30.0	0.0	0.0

7.1.5 Structures—Integrated LCT

The structural configuration of the original LCT and the integrated-LCT are the same with a tubular space frame and sheet construction. The mass of the integrated LCT is reduced relative to the original LCT by eliminating the floor support structure. The support platform of the LSAM is utilized for supporting the internal hardware and instrumentation. The external dimensions of length, width, and height remain the same. Table 7.3 lists the structures MEL.

TABLE 7.3—INTEGRATED LCT STRUCTURES AND MECHANICAL SYSTEMS DETAILED MEL

WBS no.	Description	Qty	Unit mass (kg)	CBE mass (kg)	Growth (%)	Growth (kg)	Total mass (kg)
1	LCT System	-	-----	282.5	17.7	49.9	332.4
1.1	LCT Tower-Integrated	-	-----	282.5	17.7	49.9	332.4
1.1.4	Structures & Mechanical Systems	-	-----	88.6	10.3	9.1	99.7
1.1.4.1	Primary Structures	-	-----	50.4	15.0	7.6	58.0
1.1.4.1.a	Legs	0	0.0	0.0	15.0	0.0	0.0
1.1.4.1.b	Boom for 802.x WLAN	1	18.0	18.0	15.0	2.7	20.7
1.1.4.1.c	Main Structure	1	32.4	32.4	15.0	4.9	37.2
1.1.4.2	Installation	-	-----	25.0	2.3	0.6	25.6
1.1.4.2.a	C&DH Installation	1	2.9	2.9	4.0	0.1	3.1
1.1.4.2.b	Communications Package Installation	1	6.4	6.4	4.0	0.3	6.7
1.1.4.2.c	Power Installation	1	3.5	3.5	4.0	0.1	3.6
1.1.4.2.d	Thermal Installation	1	1.8	1.8	4.0	0.1	1.8
1.1.4.2.e	Attachment fittings to LSAM	1	10.4	10.4	0.0	0.0	10.4
1.1.4.3	Mechanisms	-	-----	13.1	7.6	1.0	14.1
1.1.4.3.a	Antenna gimbals - S/Ka band no.1	2	4.4	8.8	4.0	0.4	9.2
1.1.4.3.b	Dish Antenna (Ka) Boom	1	4.3	4.3	15.0	0.6	5.0

7.1.6 Thermal Control—Integrated LCT

Table 7.4 shows the thermal MEL for the integrated LCT.

TABLE 7.4—INTEGRATED LCT THERMAL CONTROL SYSTEM DETAILED MEL

WBS no.	Description	Qty	Unit mass (kg)	CBE mass (kg)	Growth (%)	Growth (kg)	Total mass (kg)
1	LCT System			282.5	17.7	49.9	332.4
1.1	LCT Tower-Integrated			282.5	17.7	49.9	332.4
1.1.5	Thermal Control (Non-Propellant)			38.8	9.9	3.9	42.7
1.1.5.1	Active Thermal Control			12.0	9.5	1.1	13.1
1.1.5.1.a	Heaters	6	0.1	0.9	15.0	0.1	1.0
1.1.5.1.b	Thermal Control/Heaters Circuit	6	0.2	1.2	18.0	0.2	1.4
1.1.5.1.c	Data Acquisition	6	1.0	6.0	10.0	0.6	6.6
1.1.5.1.d	Thermocouples	150	0.010	1.5	5.0	0.1	1.6
1.1.5.1.e	Thermal Control Switch	12	0.2	2.4	5.0	0.1	2.5
1.1.5.1.f	Tower Heaters	0	0.1	0.0	0.0	0.0	0.0
1.1.5.2	Passive Thermal Control			26.9	10.1	2.7	29.6
1.1.5.2.a	Heat Sinks	6	3.5	20.8	10.0	2.1	22.9
1.1.5.2.b	Heat Pipes	6	0.5	3.2	13.0	0.4	3.7
1.1.5.2.c	Radiators	0	5.2	0.0	13.0	0.0	0.0
1.1.5.2.d	MLI	1	1.4	1.4	10.0	0.1	1.6
1.1.5.2.e	Temperature sensors	50	0.0	0.5	5.0	0.0	0.5
1.1.5.2.f	Phase Change Devices	0	0.0	0.0	0.0	0.0	0.0
1.1.5.2.g	Thermal Coatings/Paint	1	0.9	0.9	5.0	0.0	1.0

7.2 Fixed Base User Radio (Mini-LCT)

The function of the Fixed Base User Radio (mini-LCT) is to provide coverage for assets deployed away from the Habitat and away from the astronauts. For example, the primary usage as envisioned by the analysis was an ISRU plant located within a crater. The mini-LCT was assumed to be deployable anywhere on the lunar surface, not just at the South Pole as was the ground rule for the original LCT designed in this session. Figure 7.3 shows a rendered image of the electronics housing of the mini-LCT. The 10 m boom extends up from out of the cropped area shown below in the graphic. All major items are labeled: Ka band antenna, radiator, boom for WLAN antenna, and the electronics housing.

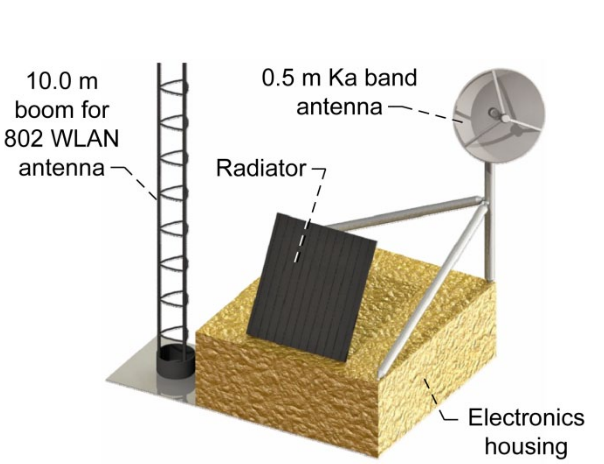


Figure 7.3—Mini-LCT deployed configuration with major subsystems highlighted.

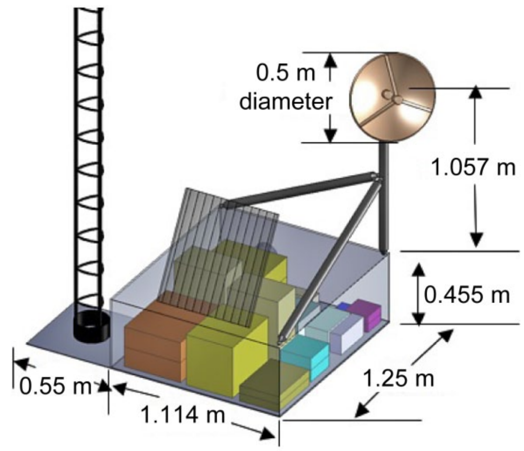


Figure 7.4—Mini-LCT with dimensions.

7.2.1 Mini-LCT Design and MEL

The mini-LCT was reduced in both size and function. Figure 7.4 shows a close up of the mini-LCT in deployed configuration. Note that the 10 m boom continues off the drawing, and is the same boom as in the original LCT design. Figure 7.4 shows a transparent view of the mini-LCT with dimensions and notional illustrations of the electronics inside.

Table 7.5 shows the top level PEL of the mini-LCT. Only the C&DH and the communications system require any power. The bottoms-up power requirement for the mini-LCT was 137 kWe. The full LCT bottoms-up power requirement was 450 kWe. Table 7.6 shows the system breakdown of the mini-LCT. Note that the total bottoms-up system level growth was 16%. The total system level mass is desired to be 30%, therefore an additional 14% growth mass (32.5 kg) was carried at the system level. The CBE mass is 236.5 kg. The growth mass of 30% is 71 kg. This brings the total mass with growth of the mini-LCT to 307.5 kg.

TABLE 7.5—MINI-LCT PEL

WBS Number	Description	Nominal Power (W)	Peak Power (W)
1	LCT System		
1.1	LCT Tower	136.60	136.6
1.1.1	LCT Communications Package (from MEL 1.2)	93.2	93.2
1.1.2	Command and Data Handling	43.4	43.4
1.1.3	Power	0	0
1.1.4	Structures & Mechanical Systems	0	0
1.1.5	Thermal Control (Non-Propellant)	0	0

TABLE 7.6—MINI-LCT MEL WITH SYSTEM GROWTH CALCULATIONS

LCT MEL (mass)	CBE (kg)	Growth (%)	Growth (kg)	Total mass (kg)	% of total mass
LCT Communications Package	49.9	20	10.1	60	21.8
LCT Bus	-----	----	----	-------	78.2
Command and Data Handling	36.3	25	9.2	45.6	16.6
Power	20.8	43	8.9	29.7	10.8
Structures and Mechanical Systems	65.9	9	6.0	71.9	26.1
Thermal Control	63.7	7	4.3	67.9	24.7
LCT Bus Mass (Without System Growth)	186.7	15.2	28.4	215.1	
LCT Bus + Comm Package Mass	236.5	16	38.5	275.0	
Desired System Growth (Contingency)	236.5	30	71.0	307.5	
Added System Level Growth (Contingency)	N/A	14	32.5	-------	
LCT Total Mass (With System Growth)	236.5	30.0	71.0	307.5	

7.2.2 Communications—Mini-LCT

The mini LCT communications system requirements were reduced from the initial LCT design in section 4.1. The signal-to-noise (SN) Tracking and Data Relay Satellite System (TDRSS) S-band radio used in the mini-LCT was the same as in the LCT. The transmitter power was reduced from 7.5 to 1 W. The 100 mb/s modem was reduced to a standard flight size. The CBE mass of the mini-LCT communications system is 49.9 kg versus the LCT communications system CBE mass of 85.6 kg.

TABLE 7.7—MINI-LCT COMMUNICATIONS SYSTEM MEL

Description One small user LCT, e.g., for ISRU H_2/H_2O or O_2 site	Qty	Unit mass (kg)	CBE mass (kg)	Growth (%)	Growth (kg)	Total mass (kg)
LCT System	-	---	49.9	20.2	10.1	59.9
LCT Communications Package	-	---	49.9	20	10.1	59.9
Gateway to Earth Hardware	0	0.0	0.0	0	0.0	0.0
Communications Hardware	-	---	27.8	-----	3.5	31.3
Ka-band/S-band HGA	-	---	1.8	-----	0.5	2.3
HGA (1 m dish)	1	1.8	1.8	30	0.5	2.3
Ka-band radio	-	---	17.8	-----	2.3	20.1
Ka band diplexer (in dual diplexer)	1	0.5	0.5	10	0.1	0.6
Ka feed (in Ka/S antenna)	1	0.9	0.9	21	0.2	1.1
2 X 1 Baseball Switch (computer controlled)	1	0.1	0.1	10	0.0	0.1
23 GHz low noise block (receiver, includes downconverter)	2	0.9	1.8	20	0.4	2.2
Ka-Band 2 x 2 Intermediate Frequency switch	1	0.1	0.1	10	0.0	0.1
100 Mb/s Modem	2	4.0	8.0	15	1.2	9.2
26 GHz power amplifier (40 W TWTA)	2	1.5	3.0	3	0.1	3.1
TWTA Electrical Power Conditioning Unit	2	1.5	3.0	10	0.3	3.3
Passive combiner network with upconverters	0	5.0	0.0	30	0.0	0.0
Passive components, couplers, switches, etc.	2	0.2	0.4	10	0.0	0.4
SN TDRSS S-band radio	-	---	8.2	-----	0.7	8.9
S band diplexer (in HGA dual diplexer and for LGA)	2	0.5	1.0	8	0.1	1.1
2 X 2 Baseball Switch (computer controlled)	1	0.1	0.1	18	0.0	0.1
S band feed (in Ka/S band antenna)	1	2.8	2.8	8	0.2	3.0
S-band cup dipole antenna	1	0.7	0.7	3	0.0	0.7
S-Band test couplers	2	0.2	0.4	3	0.0	0.4
6 Mb/s transceiver	2	1.6	3.2	10	0.3	3.5
Onboard Network and Avionics	-	---	1.0	-----	0.2	1.2
Network Hardware	-	---	1.0	-----	0.2	1.2
Router/Encryption Device	2	0.5	1.0	15	0.2	1.2
Ion trap space clock with distribution amplifier	0	2.0	0.0	20	0.0	0.0
Lunar Surface Network	-	---	16.5	-----	5.5	22.0
Wireless LAN (802.xx)	-	---	11.0	-----	4.4	15.4
Base Station (802.16e)	2	5.5	11.0	40	4.4	15.4
24 x 1 switch	0	2.0	0.0	10	0.0	0.0
WLAN Antenna	-	---	5.5	-----	1.1	6.6
Sector antenna	1	5.5	5.5	20	1.1	6.6
Subtotal	-	---	45.3	-----	9.1	54.4
Cabling to connect internal components	-	---	4.5	21	1.0	5.5
Total	-	---	49.9	-----	10.1	59.9

7.2.3 C&DH—Mini-LCT

For the avionics system, since the LCT no longer has to speak to LRS, and only to local assets, the atomic clock has been removed. In addition, the expectation is that the data recorders can be reduced to store an order of magnitude less of data than the original LCT design.

TABLE 7.8—MINI-LCT C&DH DETAILED MEL

WBS no.	Description	Qty	Unit mass (kg)	CBE mass (kg)	Growth (%)	Growth (kg)	Total mass (kg)
1	LCT System	-	-----	236.5	16.3	38.5	275.0
1.1	Mini LCT Tower	-	-----	236.5	16.3	38.5	275.0
1.1.2	Command and Data Handling	-	-----	36.3	25.4	9.2	45.6
1.1.2.1	Electronics	-	-----	25.0	19.5	4.9	29.9
1.1.2.1.a	Data recorder	2	1.1	2.2	20.0	0.4	2.6
1.1.2.1.b	General Avionics Processor	2	11.0	22.0	20.0	4.4	26.4
1.1.2.1.c	Time Generation Unit	2	0.4	0.8	3.0	0.0	0.8
1.1.2.1.d	Star Tracker	0	0.0	0.0	0.0	0.0	0.0
1.1.2.2	Antenna controls	-		0.0	0.0	0.0	0.0
1.1.2.2.a	Antenna control electronics S/Ka-band no. 1	0	0.0	0.0	0.0	0.0	0.0
1.1.2.2.b	Antenna control electronics S/Ka-band no. 2	0	0.0	0.0	0.0	0.0	0.0
1.1.2.2.c	Misc no.1	0	0.0	0.0	0.0	0.0	0.0
1.1.2.3	Cabling and associated hardware	-	-----	11.3	38.4	4.4	15.7
1.1.2.3.a	Command and Control Harness (data)	1	2.9	2.9	50.0	1.5	4.4
1.1.2.3.b	Fiber Optic Comm Port	2	2.2	4.4	20.0	0.9	5.3
1.1.2.3.c	Fiber Optic Cabling and reel	1	4.0	4.0	50.0	2.0	6.0
1.1.2.4	Misc	-		0.0	0.0	0.0	0.0
1.1.2.4.a	Atomic Clock	0	2.0	0.0	30.0	0.0	0.0

7.2.4 Power—Mini-LCT

Table 7.9 lists the items in the power system MEL.

TABLE 7.9—MINI-LCT POWER SYSTEM DETAILED MEL

WBS no.	Description	Qty	Unit mass (kg)	CBE mass (kg)	Growth (%)	Growth (kg)	Total mass (kg)
1	LCT System	-	-----	236.5	16.3	38.5	275.0
1.1	Mini LCT Tower	-	-----	236.5	16.3	38.5	275.0
1.1.3	Power	-	-----	20.8	42.9	8.9	29.7
1.1.3.3	Power Management & Distribution	-	-----	20.8	42.9	8.9	29.7
1.1.3.3.a	Power management/control electronics	1	6.5	6.5	30.0	1.9	8.4
1.1.3.3.b	Power distribution/monitoring wiring harness	1	2.8	2.8	50.0	1.4	4.1
1.1.3.3.c	Long distance power transmission cable (270 v)	1	10.7	10.7	50.0	5.3	16.0
1.1.3.3.d	Long distance power transmission cable spool	1	0.9	0.9	30.0	0.3	1.2

7.2.5 Structures—Mini-LCT

The structural configuration of the original LCT and the mini-LCT are the same with a tubular space frame and sheet construction. The length of the mini-LCT is 27 in. (0.7 m) less than the original LCT. The width and the height remained unchanged. Reducing the volume of the necessary equipment and improving the packaging accomplished the reduction in overall length. The geometric change provided an approximately 30% reduction in structural mass.

TABLE 7.10—MINI-LCT STRUCTURES AND MECHANISMS DETAILED MEL

WBS no.	Description	Qty	Unit mass (kg)	CBE mass (kg)	Growth (%)	Growth (kg)	Total mass (kg)
1	LCT System	-	----	236.5	16.3	38.5	275.0
1.1	LCT Tower-Integrated	-	----	236.5	16.3	38.5	275.0
1.1.4	Structures & Mechanical Systems	-	----	65.9	9.1	6.0	71.9
1.1.4.1	Primary Structures	-	----	32.2	15.0	4.8	37.0
1.1.4.1.a	Legs	0	0.0	0.0	15.0	0.0	0.0
1.1.4.1.b	Boom for 802.x WLAN	1	18.0	18.0	15.0	2.7	20.7
1.1.4.1.c	Main Structure	1	14.1	14.1	15.0	2.1	16.2
1.1.4.1.d	Self-Leveling hardware	0	0.0	0.0	15.0	0.0	0.0
1.1.4.2	Installation	-	----	22.8	2.2	0.5	23.3
1.1.4.2.a	C&DH Installation	1	1.5	1.5	4.0	0.1	1.5
1.1.4.2.b	Communications Package Installation	1	6.4	6.4	4.0	0.3	6.7
1.1.4.2.c	Power Installation	1	1.9	1.9	4.0	0.1	1.9
1.1.4.2.d	Thermal Installation	1	2.6	2.6	4.0	0.1	2.7
1.1.4.2.e	Attachment fittings to LSAM	1	10.4	10.4	0.0	0.0	10.4
1.1.4.3	Mechanisms	-	----	10.9	6.1	0.7	11.6
1.1.4.3.a	Separation mechanism-LSAM Interface mount	0	0.0	0.0	10.0	0.0	0.0
1.1.4.3.b	Antenna Attachment - S/Ka band no. 1	0	0.0	0.0	0.0	0.0	0.0
1.1.4.3.c	Antenna gimbals - S/Ka band no. 1	2	4.4	8.8	4.0	0.4	9.2
1.1.4.3.d	Antenna Attachment - S/Ka band no. 2	0	0.0	0.0	0.0	0.0	0.0
1.1.4.3.e	Antenna gimbals - S/Ka band no. 2	0	0.0	0.0	0.0	0.0	0.0
1.1.4.3.f	Environmental Shield	0	0.0	0.0	0.0	0.0	0.0
1.1.4.3.g	SPU cable deployment system	0	0.0	0.0	0.0	0.0	0.0
1.1.4.3.h	Dish Antenna (Ka) Boom	1	2.1	2.1	15.0	0.3	2.4

7.2.6 Thermal—Mini-LCT

The heat generated by the electronics has been reduced with the reduction in command and data handing and communications components, therefore, thermal system has reduced the size of the radiator required from that of the original LCT design. In addition, the requirement to heat the 806 WLAN boom has also been reduced.

TABLE 7.11—MINI-LCT THERMAL CONTROL SYSTEM DETAILED MEL

WBS no.	Description	Qty	Unit mass (kg)	CBE mass (kg)	Growth (%)	Growth (kg)	Total mass (kg)
1	LCT System	-	--------	236.5	16.3	38.5	275.0
1.1	Mini LCT Tower	-	--------	236.5	16.3	38.5	275.0
1.1.5	Thermal Control	-	--------	63.7	6.7	4.3	67.9
1.1.5.1	Active Thermal Control	-	--------	17.0	6.7	1.1	18.1
1.1.5.1.a	Heaters	6	0.1	0.9	15.0	0.1	1.0
1.1.5.1.b	Thermal Control/Heaters Circuit	6	0.2	1.2	18.0	0.2	1.4
1.1.5.1.c	Data Acquisition	6	1.0	6.0	10.0	0.6	6.6
1.1.5.1.d	Thermocouples	150	0.010	1.5	5.0	0.1	1.6
1.1.5.1.e	Thermal Control Switch	12	0.2	2.4	5.0	0.1	2.5
1.1.5.1.f	Tower Heaters	50	0.1	5.0	0.0	0.0	5.0
1.1.5.2	Passive Thermal Control	-	--------	46.7	6.7	3.1	49.8
1.1.5.2.a	Heat Sinks	6	3.5	20.8	10.0	2.1	22.9
1.1.5.2.b	Heat Pipes	6	0.5	3.2	13.0	0.4	3.7
1.1.5.2.c	Radiators	1	2.9	2.9	13.0	0.4	3.3
1.1.5.2.d	MLI	1	1.4	1.4	10.0	0.1	1.6
1.1.5.2.e	Temperature sensors	50	0.0	0.5	5.0	0.0	0.5
1.1.5.2.f	Phase Change Devices	0	0.0	0.0	0.0	0.0	0.0
1.1.5.2.g	Thermal Coatings/Paint	1	0.9	0.9	5.0	0.0	1.0
1.1.5.2.h	RHU (if applicable)	0	0.0	0.0	0.0	0.0	0.0
1.1.5.2.i	Radiator MMOD	1	0.4	0.4	10.0	0.0	0.4
1.1.5.2.j	Tower MLI	1	16.6	16.6	0.0	0.0	16.6

Appendix A.—Acronyms and Abbreviations

AO	Announcement of Opportunity
ARD	Architecture Requirements Document
AWG	American Wire Gauge
BAE	British Aerospace
C&DH	Command and Data Handing
CBE	Current Best Estimate
CEV	Crew Exploration Vehicle
Comm	Communications
COMPASS	COlaborative Modeling and Parametric Assessment of Space Systems
CONOPS	Concept of Operations
DTE	Direct to Earth
EIRP	effective isotropic radiated power
EMI	electromagnetic interference
FOM	figure of merit
FTE	full time equivalent
GLIDE	GLobal Integrated Design Environment
GPS	global positioning system
GRC	NASA Glenn Research Center
GSFC	NASA Goddard Space Flight Center
HF	High Frequency
HGA	high gain antenna
HQ	NASA Headquarters
IOS	internetwork operating system
ISRU	in situ resource utilization
JPL	NASA Jet Propulsion Laboratory
LAN	local area network
LAT2	Lunar Architecture Team 2
LCT	Lunar Communications Terminal
LGA	Low gain antenna
LRO	Lunar Reconnaissance Orbiter
LRS	Lunar Relay Satellite
LSAM	Lunar Surface Access Module
MEL	Master Equipment List
MGA	mass growth allowance
MLI	multi-layer insulation
MMOD	Micrometeoroid object damage
MPU	Mobile Power Unit
NASA	National Aeronautics and Space Administration
Nav	navigation
OTH	over the horizon
PEL	Power Equipment List
PMAD	Power Management and Distribution
RAID 5	redundant array of independent disks
RHU	Radioisotope Heater Unit
RFI	radio frequency interference
RTOS	Real Time Operating System
SN	signal-to-noise
SPU	Space Power Unit
SLOC	source lines of code
TDRSS	Tracking and Data Relay Satellite System
TRL	Technology Readiness Level
USO	ultra-stable oscillator
WAN	wide area network
WLAN	wireless local area network

Appendix B.—Rendered Design Drawings

B.1 Rendered Design Drawings—LCT

This section captured the rendered drawings of the LCT and its subsequent trades designed during this study. They may be redundant from figures used throughout this report. Figure B.1 shows the LCT in the stowed configuration. See Figure 3.1 for dimensions of the electronics box. Figure B.2 shows the deployed stand alone LCT. See Figure 3.1 for dimensions of the deployed configuration.

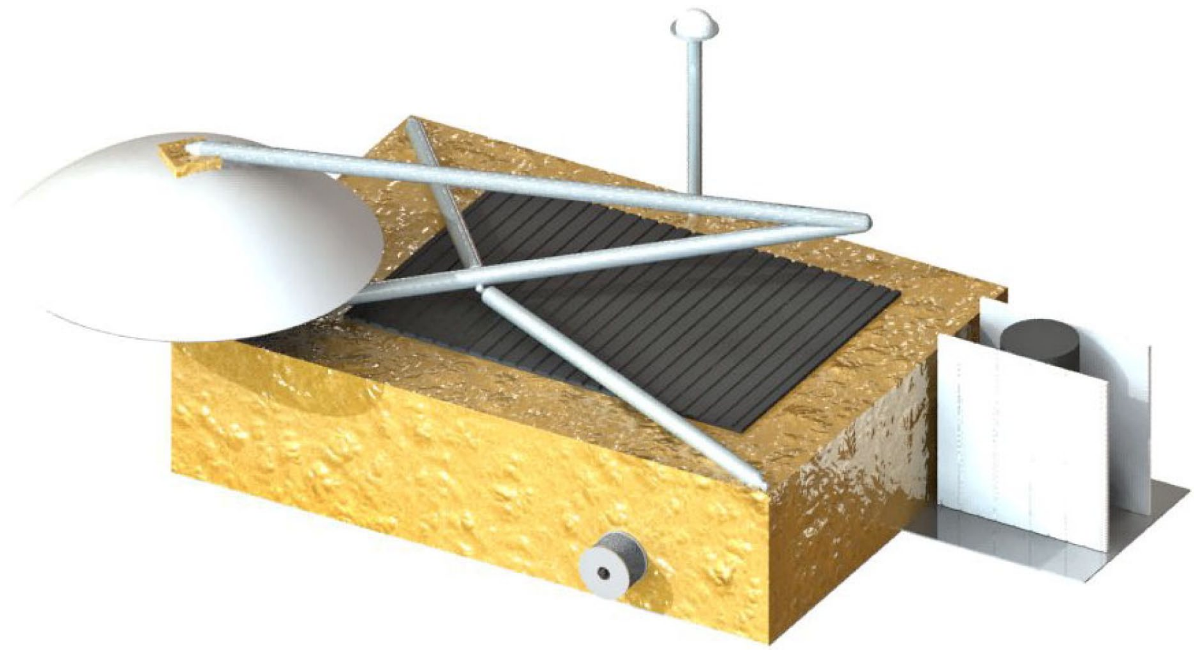


Figure B.1—Stowed configuration of the stand alone LCT.

Figure B.2—Stand alone LCT in deployed configuration.

B.2 Rendered Design Drawings—Integrated LCT

Figure B.3 shows the LCT integrated with the minimum ascent Habitat configuration in the stowed position. Now that the 10 m antenna dish is mounted on top of a boom and this boom collapses down in the stowed configuration with the antenna dish facing down. Figure B.3 and Figure B.4 show two views of the LCT integrated into the minimum ascent Habitat configuration in the deployed position. Note that the minimum ascent stage has departed from the lunar surface.

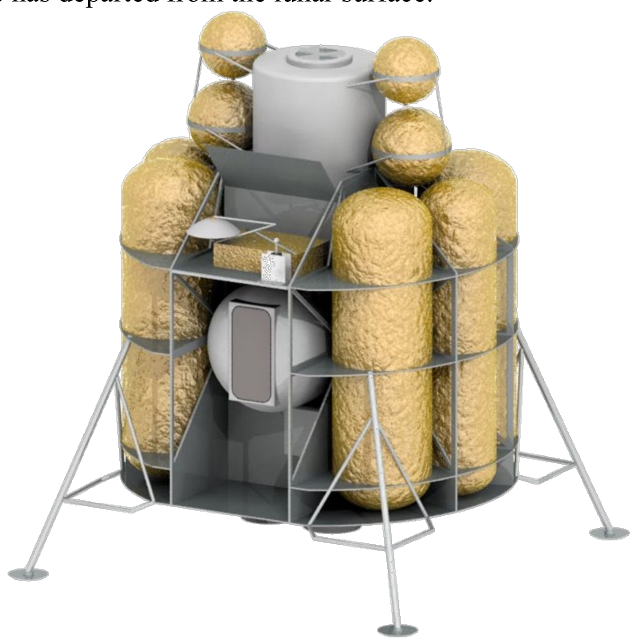


Figure B.3—Integrated LCT in stowed position on current mini-hab Lunar Lander.

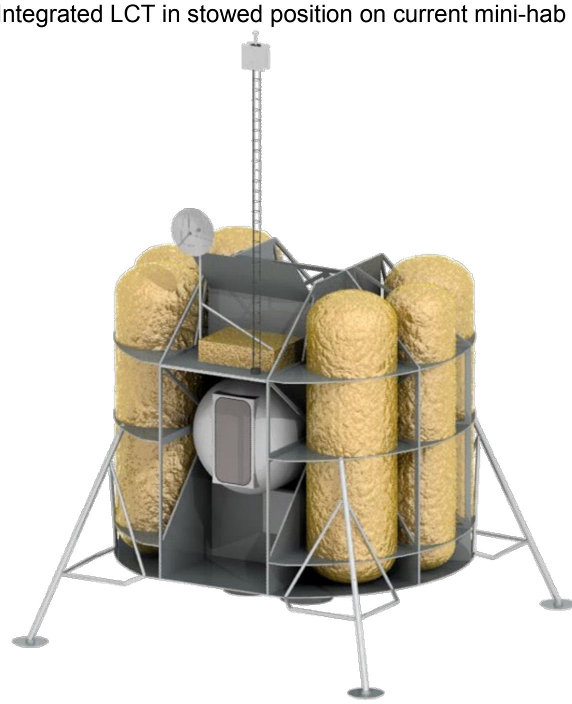


Figure B.4—Integrated LCT in deployed position on current mini-hab Lunar Lander.

Figure B.5—Integrated LCT in deployed position on current mini-hab Lunar Lander, side view.

B.3 Rendered Design Drawings—Mini-LCT

Figure B.6 shows the mini-LCT in the deployed configuration.

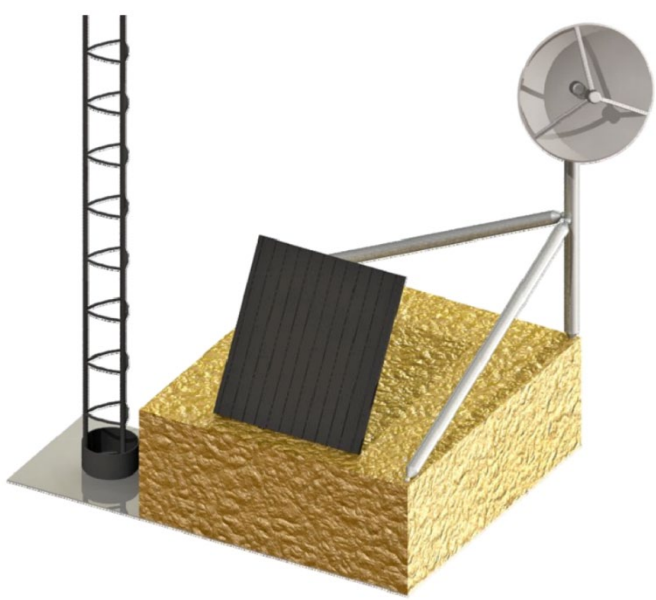


Figure B.6—Mini-LCT in deployed configuration.

Appendix C.—Study Participants

Lunar Communications Terminal (LCT) Design Session			
Subsystem	**Name**	**Center**	**Email**
LAT2 Comm and Nav Lead	Jim Shier	HQ	James.Schier-1@nasa.gov
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13. SUPPLEMENTARY NOTES

14. ABSTRACT
The Lunar Communications Terminal (LCT) COllaborative Modeling and Parametric Assessment of Space Systems (COMPASS) session designed a terminal to provide communications between lunar South Pole assets, communications relay to/from these assets through an orbiting Lunar Relay Satellite (LRS) and navigation support. The design included a complete master equipment list, power requirement list, configuration design, and brief risk assessment and cost analysis. The Terminal consists of a pallet containing the communications and avionics equipment, surrounded by the thermal control system (radiator), an attached, deployable 10-m tower, upon which were mounted locally broadcasting and receiving modems and a deployable 1 m diameter Ka/S band dish which provides relay communications with the lunar relay satellites and, as a backup, Earth when it is in view. All power was assumed to come from the lunar outpost Habitat. Three LCT design options were explored: a stand-alone LCT servicing the manned outpost, an integrated LCT (into the Habitat or Lunar Lander), and a mini-LCT which provides a reduced level of communication for primarily robotic areas dealing as in situ resource utilization (ISRU) and remote science. Where possible all the designs assumed single fault tolerance. Significant mass savings were found when integrating the LCT into the Habitat or Lander but increases in costs occurred depending upon the level of man rating required for such designs.

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